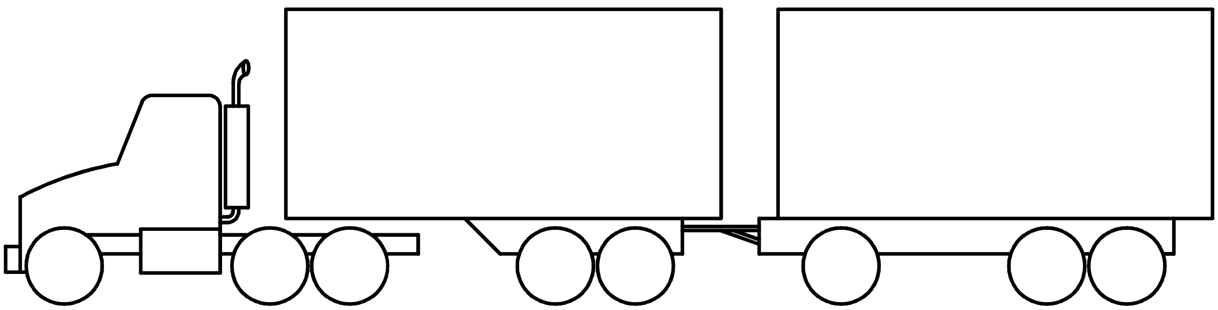
BRIDGE ANALYSIS GUIDE

2005 Edition, Part 1



MDOT
Michigan Department of Transportation

MICHIGAN DEPARTMENT OF TRANSPORTATION

CONSTRUCTION AND TECHNOLOGY SUPPORT AREA

MICHIGAN DEPARTMENT OF TRANSPORTATION
BRIDGE ANALYSIS GUIDE

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MICHIGAN DEPARTMENT OF TRANSPORTATION
BRIDGE ANALYSIS GUIDE

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Chapter 1

INTRODUCTION

January 3, 2002

MICHIGAN DEPARTMENT OF TRANSPORTATION
BRIDGE ANALYSIS GUIDE

INTRODUCTION

Purpose of the Bridge Analysis Guide

The Michigan Bridge Analysis Guide (the Guide) has been prepared to assist engineers with and to promote uniformity in analyzing highway bridges for load-carrying capacity. The process of preparing a bridge load capacity analysis has many discrete steps, including gathering physical data for the specific bridge, selecting the appropriate truck type(s), choosing the correct live load distribution factor and performing the actual analysis. This guide is structured to inform and lead the user through all the required process steps, provide completed examples and list references for further information.

The requirements for load rating of highway bridges can be found in the American Association of State Highway and Transportation Officials (AASHTO) publication, Manual for Condition Evaluation of Bridges, Second Edition, 1994 with Interim Revisions through 2000. This Guide has been prepared using that manual as a primary source of information. The Load Factor (LF) method has been used throughout this Guide.

Purpose of Load Rating

Bridge load capacity analysis is required by federal regulation, the purpose of which is to assure the structure owner, and indirectly the highway user, that each bridge is safe for use by the motoring public. Through load capacity analysis, a bridge may be discovered to be incapable of safely carrying some legal loads. In that circumstance, it may be necessary to publicly “post” the bridge for the reduced safe load, or in the extreme case, to close the bridge. In addition, for those occasions when loads beyond the range of standard legal vehicles (or “permit” loads) need to use a specific structure, load capacity analysis can provide answers about which loads are safely acceptable.

Qualifications and Responsibilities

The individual with overall responsibilities for load rating bridges should be a licensed professional engineer and preferably shall have a minimum of 5 years of bridge design and inspection experience. The engineering skills and knowledge necessary to properly evaluate bridges may vary widely depending on the complexity of the bridge involved. The specialized skills and knowledge of other engineers may be needed to ensure proper evaluation.

Basic Definitions (see Chapter 12 for more definitions)

Inventory Rating. The Inventory Rating represents the normal live load capacity of a bridge using the current load distribution factors, calculated with the current Load Factor Methods, but reflects the existing member and material deterioration. The AASHTO HS loading configuration is the applied live load. The load rating is expressed in terms of HS-type loadings. This load rating is intended to represent the load that can be safely carried by the bridge on a frequently repeated and continuing basis.

Federal Operating Rating. The Operating Rating represents the maximum live load capacity of a bridge calculated as noted above for the Inventory Rating, but with a reduced load factor for Live Load. The AASHTO HS loading configuration is used as the applied load, however the load is reported to MDOT in terms of MS-type loading. (The metric equivalent of HS loading) This load rating is intended to represent loads that can be safely carried by the bridge on an infrequent basis. Allowing unlimited numbers of vehicles to use a bridge at the Operating Level may shorten the life of the bridge.

Michigan Operating Rating. Michigan law allows legal loads that are in excess of the gross weights for standard H and HS-type loads. For the Michigan Operating Rating, bridges are to be analyzed with operating load factors for the ability to carry all Michigan legal loads. The vehicle types to be investigated are the three AASHTO legal vehicles and all Michigan legal vehicles. Michigan legal vehicles include all legal single-unit trucks, two-unit trucks (tractors with a trailer) and three-unit trucks (a tractor with two trailers). The Michigan Operating Rating represents loads that can be safely carried by the bridge on an infrequent basis. This rating may sometimes be referred to as the *Legal Load Rating*.

Load Posting. When it is discovered that a bridge can not safely carry all Michigan legal loads at the operating level, the bridge is posted with a sign indicating the maximum weight of vehicles of all three types (one-unit, two-unit and three-unit) that can safely use the bridge. Agencies may choose to post bridges for less than the calculated capacity, or to post at the inventory rating level, in order to extend the life of the structure.

Overloads or Permit Loads. Occasionally, vehicles that are heavier than Michigan legal loads, or that have axle configurations or axle loads that are not allowed by Michigan law, may need to use the highways and may cross specific highway bridges. Those vehicles can be said to be “overloads” and are required to obtain a permit from the agency owning the highway and bridges in question. It is prudent to analyze the capacity of the specific bridges to be crossed for their ability to safely carry the overload. Overload analysis is ordinarily done at the Operating level. Permits are then issued or denied based on the bridge analysis.

Federal Regulations that Govern Load Rating

The requirement to analyze highway bridges for capacity stems from federal law and can be found in the National Bridge Inspection Standards (NBIS) October 1988, within the Code of Federal Regulations. Specifically, Title 23, Part 650, Subpart C, 650.303 (c) reads in part, “Each structure. . .shall be rated as to its safe load carrying capacity in accordance with Section 4 of the AASHTO Manual.”

The requirements to maintain records related to bridge inspections and ratings can be found in the NBIS 650.311 (a), which reads in part, “Each State shall prepare and maintain an inventory of all bridge structures. . .” and “. . .certain structure inventory and appraisal data must be collected and retained within the various departments. . .”

When to Perform a Load Rating

In general, load ratings are performed on a bridge when one of five events has occurred: 1) the bridge is new and has not been previously rated, 2) the bridge has had a significant alteration that may affect the capacity of the bridge, 3) the bridge has incurred damage that affects the capacity, 4) a key component of the structure has deteriorated such that the previous load rating is no longer valid or 5) a request has been made to permit an overload vehicle to use the bridge.

New bridges must be load rated in order to comply with the Code of Federal Regulations requirements cited above. Rated capacities for new bridges are submitted to the MDOT and become the first recorded information retained about that topic.

In the second instance, if a bridge element has been repaired, rehabilitated, reconstructed or altered in a significant way, a load rating must be performed. This load rating could be triggered by such items as a deck overlay, the addition of a heavier railing, a new deck, a new superstructure, beam repairs, new beams, widening, significant substructure repair or any other rehabilitation that would affect the ability of the structure to carry load. The analyst must be aware of any changes in dead load that result from the work performed on the bridge.

The third case could be represented by an accident in which a vehicle struck a beam or substructure unit and significant damage occurred. The nature and extent of the damage would need to be included in modeling the structure for the new load rating.

In the fourth instance, a new load rating would be initiated after a field inspection indicated that a key element had deteriorated to a level not represented in the previous load rating. This would include items such as beam flange or web section loss, deck deterioration, substructure unit section loss or being out of plumb.

In the final instance, a permit application may have been submitted for an overload vehicle to travel over a particular bridge or series of bridges along a proposed route. If a bridge has not been analyzed previously for this particular overload, that task must be completed before a answer to the permit application can be returned.

All load ratings should be performed based on the result of a recent inspection of the bridge and where possible the design and/or as-built plans for the structure must be reviewed.

Michigan's Heavy Trucks.

A key feature of Bridge Load Ratings in Michigan is the inclusion of all Michigan legal loads. Michigan law allows the use of trucks that far exceed the federal limit of 80,000 lb. Maximum total weights are not directly controlled by Michigan law; however, weights are indirectly controlled by a combination of maximum legal vehicle lengths, maximum legal axle loads and axle spacing. The combined effect of those items yields legal trucks that can weigh as much as 164,000 lb. Individual axle loads and tandem axle loads have a variety of legal limits based on spacing, but the overall maximums are limited to the federal limits for axle weights.

While it should be noted that a small percentage of commercial vehicles in Michigan operates at greater than the federal limit of 80,000 lb, the concentration of these heavy vehicles varies widely throughout the state. Some rural locations may rarely see a vehicle greater than 80,000 lb, while other areas, such as near an aggregate pit or manufacturing facility may experience frequent passage of heavy vehicles. As noted above, Operating Ratings are to be performed with the inclusion of all Michigan legal loads.

Chapter 2

MICHIGAN LEGAL LOADS

September 28, 2001

MICHIGAN LEGAL LOADS

Introduction

In an effort to provide an overall understanding of the Michigan Legal Loads, a summary of the evolution of legal loads nationwide is presented, followed by the background for legal loads in Michigan. The purpose is to give the document user the information needed to fully understand the loads to be used in rating bridges in Michigan.

Federal Regulations

Based on an American Association of State Highway Officials (AASHO) policy adopted in 1946, the first federal Truck Size and Weight (TS&W) limits were enacted in the Federal-Aid Highway Act of 1956. The federal involvement in setting interstate TS&W limits was motivated by the increased federal highway funding to the states in the years leading to the 1956 Act. The Act established the following limits:

- Single-axle weight limit of 18,000 lb;
- Tandem-axle weight limit of 32,000 lb;
- Gross Vehicle Weight (GVW) of 73,280 lb; and
- Maximum width limit of 96 inches.
- Alternate Military Loading of tandem axles spaced at 4' weighing 24,000 lbs each.

These limits were qualified by a “grandfather clause” that allowed continued operation of heavier trucks on the new interstate system consistent with state limits in effect prior to July 1, 1956.

In 1974, the limits were increased as follows, based on the Federal-Aid Highway Amendments:

- Single-axle weight limit of 20,000 lb;
- Tandem-axle weight limit of 34,000 lb; and
- Gross Vehicle Weight (GVW) of 80,000 lb.

Additional regulations followed in the Surface Transportation Assistance Act (STAA) of 1982 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. However, these regulations dealt primarily with size restrictions. The 1974 weight limits are still applicable today on the interstate system.

State Regulations

The extension of grandfather rights has allowed the states to continue operation of vehicles on state and interstate highways in excess of the limits mandated by federal regulations. These rights allowed individual states continued control of size and weight limits. The limits were influenced by three different grandfather rights provisions. The first, enacted in 1956, addressed axle weights, gross weights and permits. The second, adopted in 1975, applied to the bridge formula and axle spacings. The third, enacted in 1991, ratified state practices regarding Longer Combination Vehicles (LCV).

Currently throughout the nation, there are 40 different combinations of weight limits that apply both on and off the interstate system. (Ref 18) As a result, each state has a different weight limit "package" consisting of different mixes of these combinations.

Michigan Regulations

The three levels of Michigan Legal loads are called Normal, Designated and Special Designated, and are described in detail below. The current legal load limits in the State of Michigan are controlled either directly by axle load limits or indirectly by a combination of vehicle length limits, permissible axle spacing, permissible axle loads and number of axles allowed by law. In all loadings shown below, the axle loads are also limited by the width of the tire. The maximum load for any wheel is 700 pounds per inch of tire width.

Figure 2.1 illustrates common legal vehicles used on Michigan roads (truck numbers 1-25).
Front axle loads are shown as 15.4 kips since the trend in the trucking industry is moving to 11 inch tire widths. Truck numbers 26-28 shown on Figure 2.1 illustrate the AASHTO analysis vehicles.

Figure 2.2 illustrates the standard AASHTO design vehicles.

<u>Normal Loading</u>

Section 257.722.1 of the Michigan Vehicle Code (Act 300 of 1949) (Ref. 21) defines "Normal" loading as follows:

- If the axle spacing is 9 ft or more between axles, the maximum axle load shall not exceed 18,000 lb.
- If the axle spacing is less than 9 ft between 2 axles but more than (or equal to) 3 ft 6 in, the maximum axle load shall not exceed 13,000 lb. (The most common tandem axle spacing is 3 ft 6 in)
- If the axles are spaced less than 3 ft 6 in apart, the maximum axle load shall not exceed 9,000 lb per axle.

The above loading sets limitations on individual axles. There is no direct maximum for the total gross vehicle weight for normal loading. There is, however, an indirect limit caused by a combination of the maximum legal length of vehicles, maximum legal axle loads, axle spacing and total number of axles allowed. The Michigan Vehicle Code allows a maximum of 11 axles for legal vehicles.

According to the Michigan Vehicle Code, the length limits are briefly summarized as follows:

- Single Vehicle: 40 ft.

- Truck tractor and Semitrailer combinations: No overall length limit, but the semitrailer is not to exceed 50 ft.

- Truck and semitrailer or trailer combinations: 65 ft, with an exception for saw logs, pulpwood and tree length poles, where the maximum overall length shall not exceed 70 ft.

- Truck Tractor and two semitrailers, or truck tractor, semitrailer and trailer combinations: no overall length limit, if the length of each semitrailer or trailer does not exceed 28.5 ft, or the overall length of the trailers in combination does not exceed 58 ft, measured from the front of the first trailer to the rear of the second trailer.

- Tow bar and saddle-mount equipment: 75 ft.

“Normal” loading defines the lowest set of maximum loadings that applies to all Michigan roads. More permissive sets of legal loads are described below.

<u>Designated Loading</u>

Roadways owned by local authorities or by the state may be “designated” to allow heavier loads. This designation is a variation to the “normal” loading mentioned above and is as follows:

- If the gross vehicle weight is less than or equal to 73,280 lb, two tandem axle assemblies shall be allowed to carry 16,000 lb per axle so long as no other axle is within 9 ft of any axle of the assembly.

- If the gross vehicle weight is more than 73,280 lb, one tandem axle assembly shall be allowed to carry 16,000 lb per axle so long as no other axle is within 9 ft of any axle of the assembly**,** and if no other tandem axle assembly in the combination of axles exceeds a gross weight of 13,000 lb per axle.

As with normal loading, designated loading has no direct maximum of the total gross vehicle weight. The gross vehicle weight is indirectly controlled by the maximum legal length of the vehicle, axle spacing, legal axle weights and the maximum number of axles.

Special Designated Loading

In general, “special designated loading” applies to interstate highways. The state Department of Transportation for other routes, or a local authority with respect to highways under its jurisdiction may also adopt this loading. The “special designated loading” may be applied to vehicles with a gross vehicle weight less than 80,000 lb. The loading constraints are as follows:

- No axle can carry a load in excess of 20,000 lb.
- No tandem axle assembly can carry a load in excess of 34,000 lb (17,000 lb per axle of the assembly).
- The overall gross vehicle weight and the weight of any combination of consecutive axles are limited by the following formula, known as the Federal Bridge Formula B:

$$W=500[LN/(N-1)+12N+36]$$

Where: W = the maximum weight in pounds that can be carried by a consecutive combination of 2 or more axles.

L = spacing in feet between the outer axles of any consecutive combination of 2 or more axles.

N = number of axles be considered in the combination.

An exception is granted for a five axle vehicle with two consecutive sets of tandem axles. That vehicle configuration may carry a gross load of 34,000 lb for each tandem if the first and last axles of the consecutive sets of tandem axles are at least 36 ft apart.

However, when the gross vehicle weight of a 5-axle vehicle exceeds 80,000 lb, the above formula can not be utilized and gross vehicle loading is then controlled by “normal” loading and “designated” loading.

HISTORY OF DESIGN LIVE LOADS

Design live loads are used during the design of a new bridge, and reconstruction or rehabilitation designs. Design live loads are not legal loads. Generally speaking, design axle loads are more severe than legal axle loads and help to provide reasonable factors of safety for slab designs.

Figure 2.2 illustrates the current design vehicles (H-20 and HS-20) set forth by AASHTO in the Standard Specifications for Highway Bridges. The MDOT has gradually adopted HS-25 as the standard design live load, beginning with interstate and primary bridges and now extending to all trunkline bridges. HS-25 is 25% heavier than HS-20. Some local agencies have also adopted HS-25 live load as their standard.

Table 2.1 presents, as a historical reference, the history of Design Live Loads in the Michigan Bridge Specifications, according to the 1983 Michigan Bridge Analysis Guide. (Ref. 8)

TABLE 2.1 History of Design Live Loads in Michigan Bridge Specifications

Year	Loading (Floor System)	Long Span Girders, Trusses	Axle Loads
Law 1907*	10 T Traction Engine		
1907, 1909	12 T Steam Rd. Roller or 10 T	100 psf	(8 T)
1911	15 T Road Roller	100 psf	(10 T)
1914, 15, 16	18 T Road Roller	100 psf (80)**	(12 T) 10' (6 T)
1920, 22	18 T Truck or 10 T	100 psf (80)**	
1923	24 T Truck (Wayne Co.)	100 psf	(16 T) 12' (8 T)
1926	H15 Truck (H20, H12.5, H10)	Eq. Lane Load	
1936	H15 or H20	Truck Train***	(12 T) 14' (3T)
1946	H15, H20, H20-S16 (Adopted by Wayne Co., 1941)	Equivalent Lane Load	
1958	H15, H20 or H20-S16 + Alt. Mil. Load	Eq. Lane Load	
1972	H20 or HS20 + Alt. Mil. Load	Eq. Lane Load	(16 T) 14' (4 T)
1973	H25 or HS25 + Alt. Mil. Load	Eq. Lane Load	(20 T) 14' (5 T)

* The 10-ton Traction Engine is not a specification but was used as a legal design load in many localities when purchasing bridges as late as 1912 per L.C. Smith. He also states that “Modern Bridge Engineers are designing bridge floors for a 15-ton Road Rollers.”
** For spans between 100 ft and 200 ft, the 100 psf load is reduced by 1 psf for every 5 additional ft. Therefore, for a 200 ft span, 80 psf would be used. The 80 psf would also control for spans longer than 200 ft.

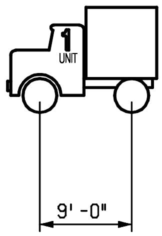
*** H15 Train is a series of H15 trucks separated by 30 ft. An H20 Train is an H15 Train with one H20 truck inserted.

Table 2.2 lists other specifications referred to in Michigan bridge designs, according to the 1983 Michigan Bridge Analysis Guide.

TABLE 2.2 Other Specifications Referred to in Michigan Bridge Designs

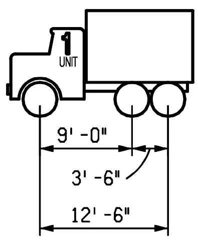
Year	Loading (Floor System)	Long Span Girders, Trusses	Axle Loads
	Niles MCRR	to 32' > 32'	
1890	8 T on axles 8' apart	100 psf (80)	(4T) 8' (4T)
1896	T. Cooper-Howell AARR	150 psf	
1909	T. Cooper’s Br. Spec. Class		
	24 T City A	100 psf	
	12 T Suburban B	100 psf	
	12 T or 18 T St. Car C		
	6 T Country D	80	
	24 T Street Car E1	Train	
	18 T Street Car E2	Train	
1903 & 1911	Saginaw - Genessee and Johnson St. 40 T Street Car	100 psf	Two tandems spaced @ 20' c to c. Axles @ 6' spacing within tandems.
1911	Grand Rapids - Leonard St. 60 T Street Car	150 psf	Two axles spaced @ 22'.
1927	60 T Street Car (Monroe)		Two tandems spaced @ 30' c to c. Axles @ 7' spacing within tandems.

TRUCK NO.
1



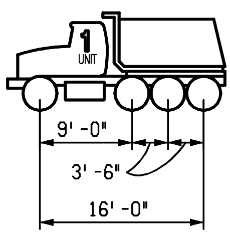
			Totals	Equivalent train load
NL (kips)	15.4	18	33.4	0.86 klf
DL (kips)	15.4	18	33.4	0.86 klf
SD (kips)	19	20	39	1.00 klf

TRUCK NO.
2



				Totals	Equivalent train load
NL (kips)	15.4	13	13	41.4	0.97 klf
DL (kips)	15.4	16	16	47.4	1.12 klf
SD (kips)	11.4	17	17	45.4	1.07 klf

TRUCK NO.
3



					Totals	Equivalent train load
NL (kips)	15.4	13	13	13	54.4	1.18 klf
DL (kips)	15.4	13	13	13	54.4	1.18 klf

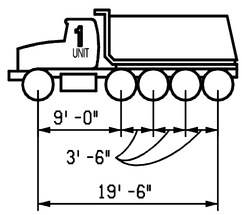
NL Denotes Normal loading

DL Denotes Designated loading

SD Denotes Special Designated loading

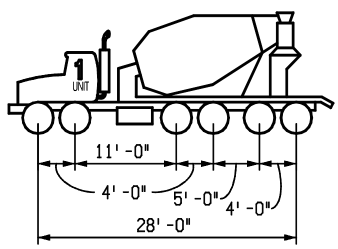
FIGURE 2.1
Michigan Legal Vehicles

TRUCK NO.
4



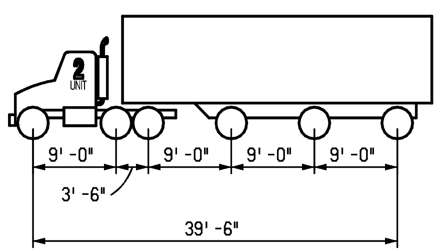
						Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	67.4	1.36 klf
DL (kips)	15.4	13	13	13	13	67.4	1.36 klf

TRUCK NO.
5



							Totals	Equivalent train load
NL (kips)	13	13	13	13	13	13	78	1.34 klf
DL (kips)	16	16	13	13	13	13	84	1.45 klf

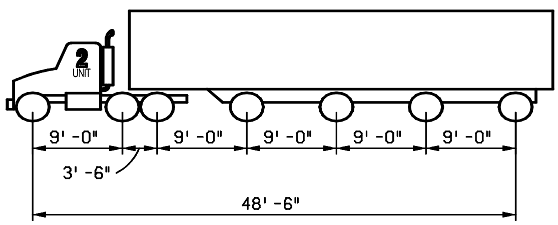
TRUCK NO.
6



							Totals	Equivalent train load
NL (kips)	15.4	13	13	18	18	18	95.4	1.37 klf
DL (kips)	15.4	16	16	18	18	18	101.4	1.46 klf

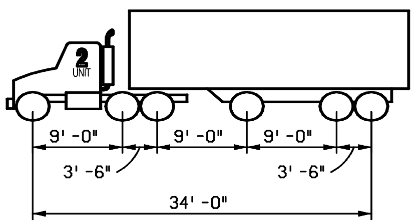
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
7



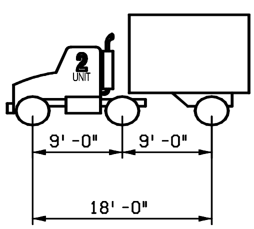
								Totals	Equivalent train load
NL (kips)	15.4	13	13	18	18	18	18	113.4	1.44 klf
DL (kips)	15.4	16	16	18	18	18	18	119.4	1.52 klf

TRUCK NO.
8



							Totals	Equivalent train load
NL (kips)	15.4	13	13	18	13	13	85.4	1.33 klf
DL (kips)	15.4	16	16	18	13	13	91.4	1.43 klf

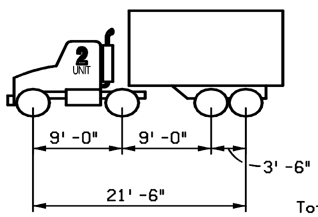
TRUCK NO.
9



				Totals	Equivalent train load
NL (kips)	15.4	18	18	51.4	1.07 klf
DL (kips)	15.4	18	18	51.4	1.07 klf
SD (kips)	10.5	19.5	19.5	49.5	1.03 klf

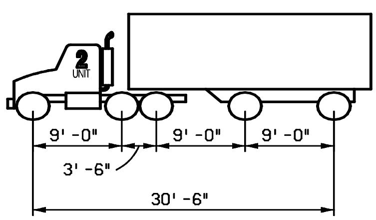
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
10



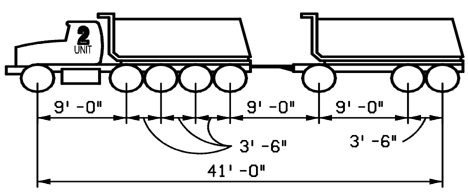
					Totals	Equivalent train load
NL (kips)	15.4	18	13	13	59.4	1.15 klf
DL (kips)	15.4	18	16	16	65.4	1.25 klf
SD (kips)	11	11.4	17	17	56.4	1.10 klf

TRUCK NO.
11



						Totals	Equivalent train load
NL (kips)	15.4	13	13	18	18	77.4	1.28 klf
DL (kips)	15.4	16	16	18	18	83.4	1.38 klf
SD (kips)	7.1	10.5	10.5	19.5	19.5	67.1	1.11 klf

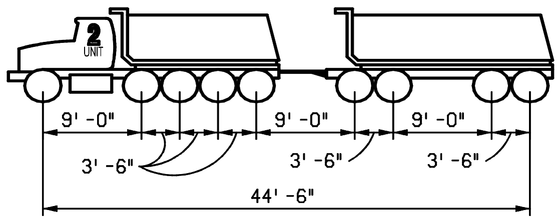
TRUCK NO.
12



									Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	18	13	13	111.4	1.57 klf
DL (kips)	15.4	13	13	13	13	18	16	16	117.4	1.65 klf

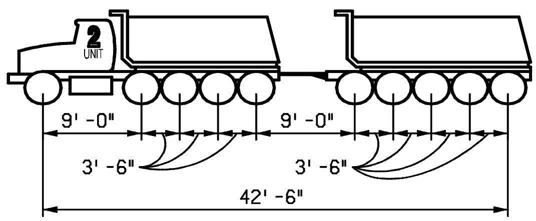
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
13



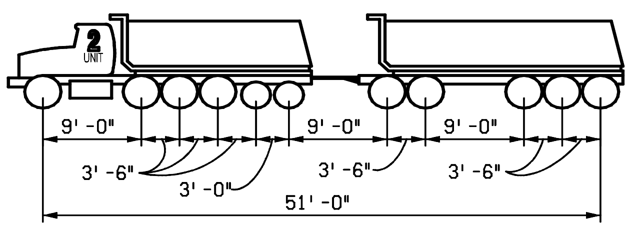
											Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13		119.4	1.60 klf
DL (kips)	15.4	13	13	13	13	13	13	16	16		125.4	1.68 klf

TRUCK NO.
14



											Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13	13	132.4	1.83 klf
DL (kips)	15.4	13	13	13	13	13	13	13	13	13	132.4	1.83 klf

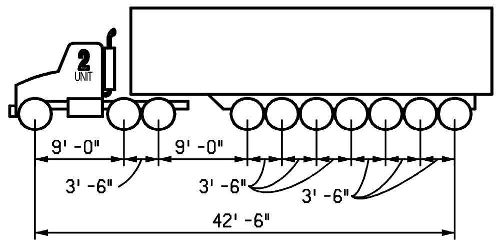
TRUCK NO.
15



												Totals	Equivalent train load
NL (kips)	15.4	13	13	13	9	9	13	13	13	13	13	137.4	1.70 klf
DL (kips)	15.4	13	13	13	9	9	16	16	13	13	13	143.4	1.77 klf

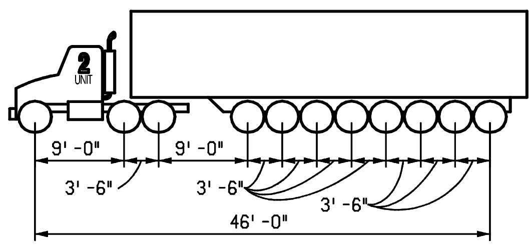
FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
16



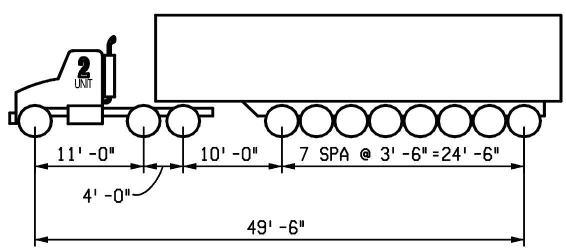
												Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13	13		132.4	1.83 klf
DL (kips)	15.4	16	16	13	13	13	13	13	13	13		138.4	1.91 klf

TRUCK NO.
17



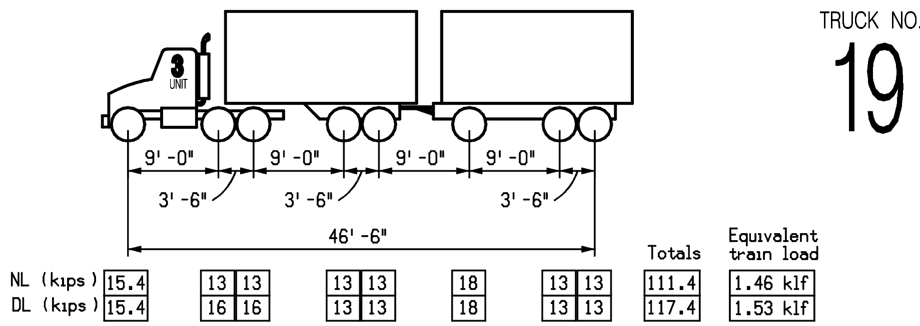
												Totals	Equivalent train load
NL (kips)	15.4	13	13	13	13	13	13	13	13	13	13	145.4	1.91 klf
DL (kips)	15.4	16	16	13	13	13	13	13	13	13	13	151.4	1.99 klf

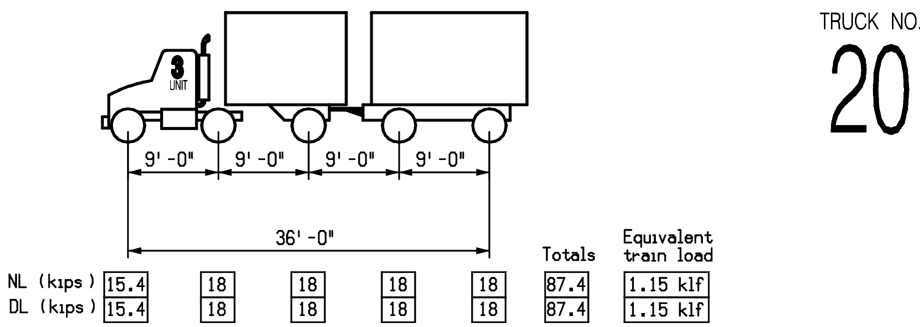
TRUCK NO.
18



												Totals	Equivalent train load
NL (kips)	18	13	13	13	13	13	13	13	13	13	13	148	1.86 klf
DL (kips)	18	16	16	13	13	13	13	13	13	13	13	154	1.94 klf

FIGURE 2.1 (Continued)
Michigan Legal Vehicles





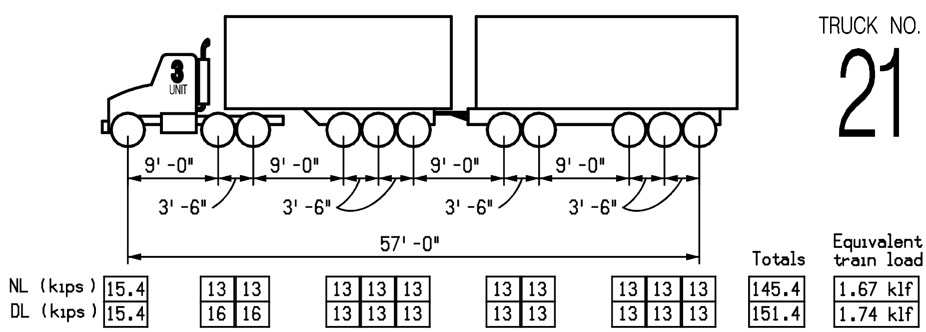
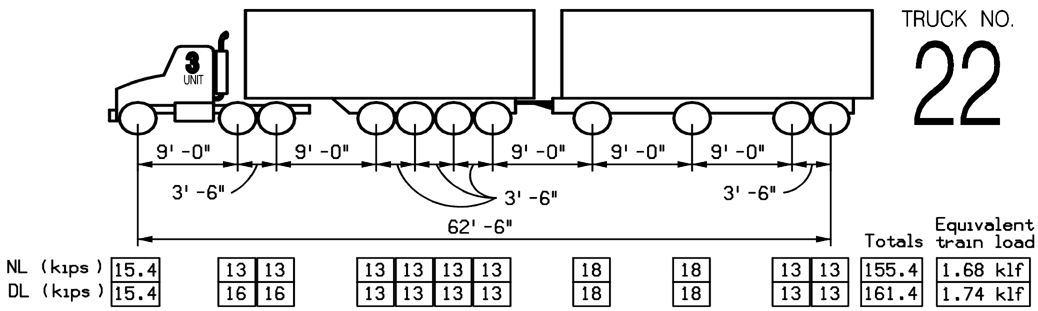
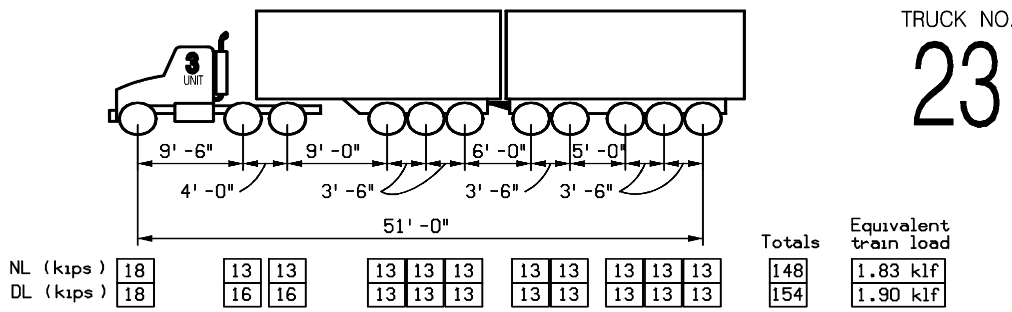


FIGURE 2.1 (Continued)
Michigan Legal Vehicles





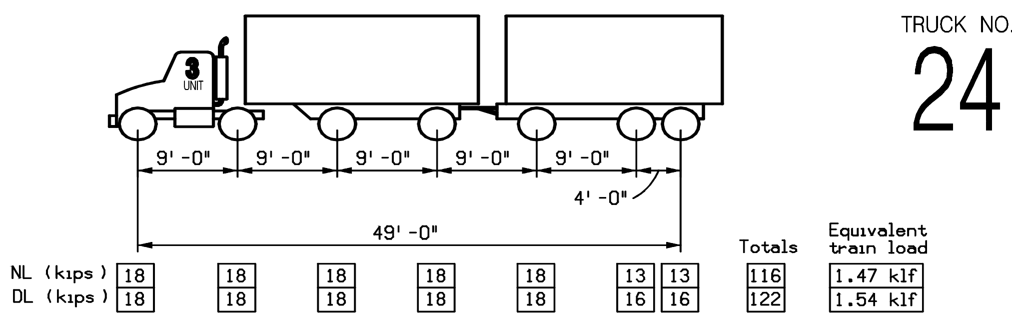
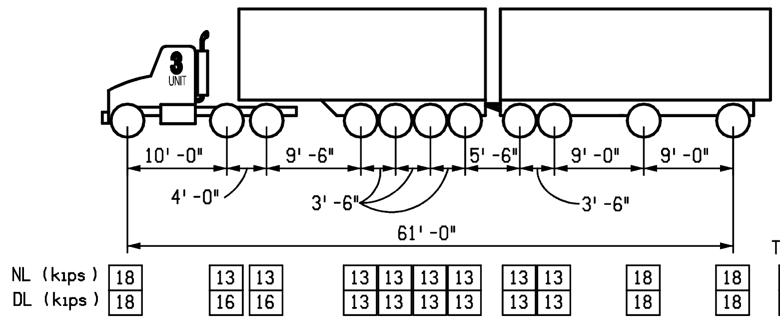
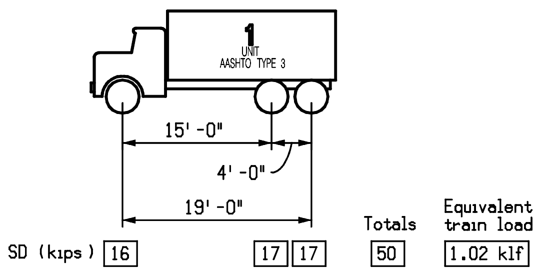


FIGURE 2.1 (Continued)
Michigan Legal Vehicles

TRUCK NO.
25



TRUCK NO.
26



TRUCK NO.
27

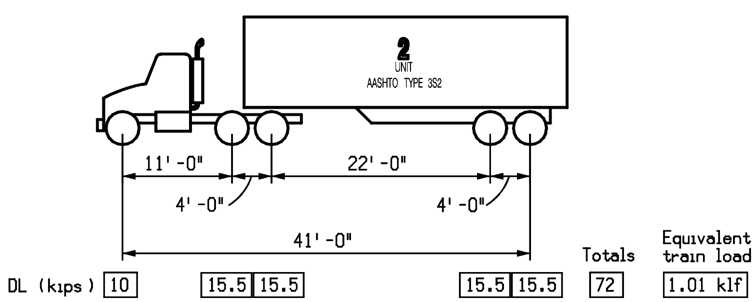
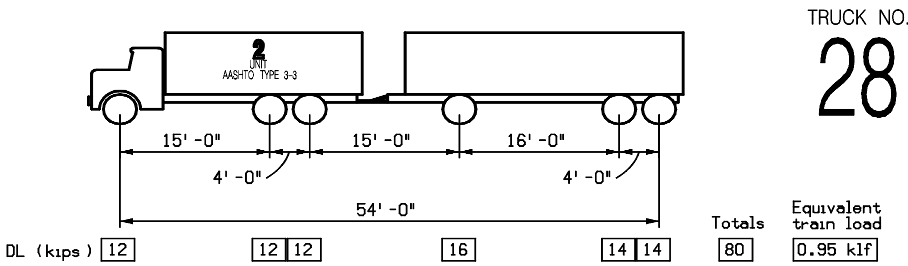


FIGURE 2.1 (Continued)
Michigan Legal Vehicles



NOTES:

NL Denotes Normal axle loading

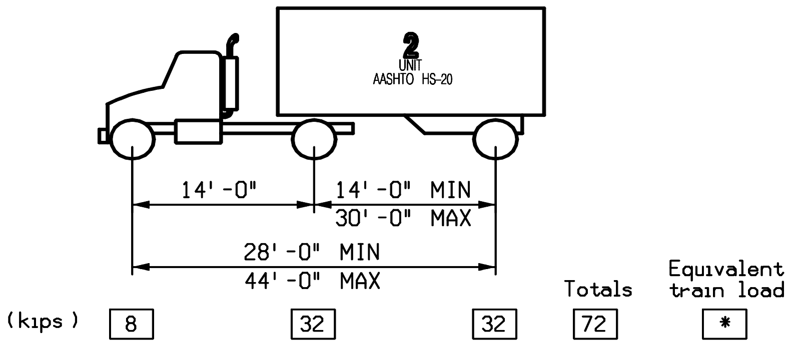
DL Denotes Designated axle loading

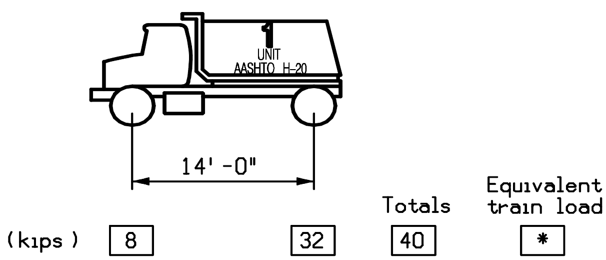
SD Denotes Special Designated axle loading

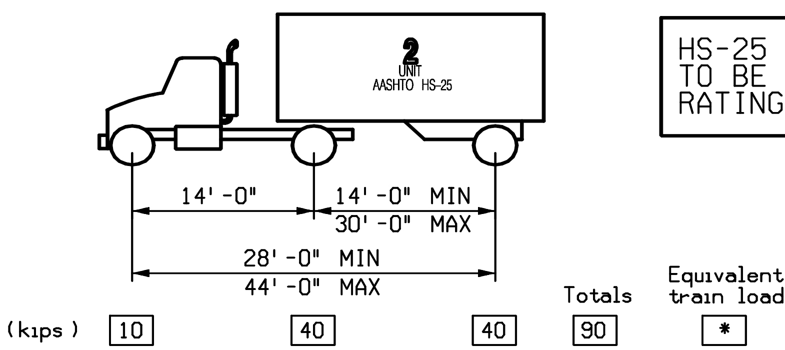
The maximum load of any tire is limited to 700 lbs per inch of tire width.

Normal, Designated and Special Designated loadings are defined in Chapter 2 of this guide.

FIGURE 2.1 (Continued)
Michigan Legal Vehicles







HS-25 TRUCKS ARE NOT TO BE USED FOR ANY LOAD RATING CALCULATIONS

NOTE:

* See Figure 3.7.6B in the AASHTO Standard Specifications for Highway Bridges.

FIGURE 2.2
Design Live Loads

Chapter 3

LEGAL LOADS IN OTHER STATES/PROVINCES AND COUNTRIES

January 3, 2002

LEGAL LOADS IN OTHER STATES AND PROVINCES

Introduction

The purpose of this chapter is to provide the engineer with the legal loads in neighboring states so that border bridges can be properly rated for both states involved. This chapter also include a brief summary of the influence of North America Free Trade Agreement (NAFTA) requirements on bridges. The information presented in this chapter was gathered from a number of sources, including interviews with personnel from the Engineering Departments of the various Departments of Transportation and the Federal Highway Administration (FHWA); Department of Transportation Internet websites and technical journal articles.

Bridge Load Ratings and Legal Vehicles in Nearby States and Provinces

Each state or province has weight and dimensional limitations for all vehicles traveling on its roads. If these limitations are exceeded, a permit must be obtained from the governing transportation agency.

The following paragraphs present a summary of the general procedures that the states or provinces nearby to Michigan use in the calculation of load ratings for their bridges. The summary includes information regarding vehicles used for the ratings and analysis methods to be used. Also included is a discussion of general size and weight limitations the jurisdiction may have.

Neighboring States/Provinces with Michigan Border Bridges

For those bridges which lie on the border of Michigan and another state, the bridge rating analyst is directed to rate the structures with Michigan legal loads, but to do so in concert with the owning agency from the neighboring state.

<u>Wisconsin</u>

The Wisconsin Department of Transportation (WisDOT) uses the AASHTO HS20-44 vehicle as well as a 190,000 lb Standard Permit Vehicle for its load ratings. The configuration of the Standard Permit Vehicle is shown in Figure 3.1. WisDOT uses the Load Factor Method for the calculation of load ratings and its own in-house software to do the ratings calculations.

The maximum legal weight of any vehicle in Wisconsin with at least 5 axles is 80,000 lb. In general, individual axle weight limitations are as follows: 13,000 lb for a steering axle and 20,000 lb for any single axle. The limitations for trucks with 4, 3 and 2 axles are 76,000 lb, 60,000 lb, and 40,000 lb, respectively. All of these limitations are further modified depending on the spacing of the axles.

The maximum height and width are 13 ft 6 in and 8 ft 6 in, respectively. Lengths are limited to 40 ft and 65 ft for single vehicles and combination vehicles, respectively (including loads).

Ontario

The Ontario Ministry of Transportation (MTO) has a standard set of “controlled vehicle loads” called “Ontario Highway Bridge Evaluation Loads (OHBEL).” These loads are designated Level 1, Level 2 and Level 3 and include truck and lane loadings for each level. The vehicle configurations are shown in Figure 3.1. MTO uses the Load Factor Method for the calculation of load ratings.

The maximum legal weight of any vehicle in Ontario is 63,500 kilograms (140,000 lb).

In general, the maximum height and width are 4.15 meters (13 ft 6 in) and 2.6 meters (8 ft 6 in), respectively. The maximum lengths for single vehicles and combination vehicles (including loads) are 12.5 meters (41 ft) and 23 meters (75 ft 5 in), respectively.

Neighboring States without Michigan Border Bridges

The following information is supplied so that owning agencies along Michigan’s borders can have basic knowledge about the legal weights and practices in other nearby jurisdictions.

Illinois

The Illinois Department of Transportation (IDOT) uses the AASHTO HS20-44 vehicle to calculate its load ratings. IDOT’s load ratings are performed in accordance with the Load Factor Method.

The maximum legal weight of any vehicle in Illinois is 80,000 lb. Permit vehicles may exceed this weight but are limited to IDOT’s “Practical Maximum Weights.” These are 120,000 lb for 6-axle vehicles, 100,000 lb for 5-axle vehicles, 76,000 lb for 4-axle vehicles, 68,000 lb for 3-axle vehicles, and 48,000 lb for 2-axle vehicles.

The general maximum height and width limitations are 13 ft 6 in and 8 ft 6 in, respectively, although IDOT has a set of legal dimensions for various configurations of trucks.

Indiana

The Indiana Department of Transportation (INDOT) uses the AASHTO H20-44 and HS20-44 vehicles to establish load ratings for their bridges. All INDOT load ratings are calculated using the Load Factor Method of analysis. INDOT's Superload Permit Section uses AASHTO Bridge Analysis and Rating System (BARS) software to calculate its load ratings.

The maximum legal weight of any vehicle in Indiana is 80,000 lb. Individual axle weights are limited to those specified by FHWA Bridge Formula B.

The maximum height and width are 13 ft 6 in and 8 ft 6 in, respectively. The limitations for length are 40 ft for a single vehicle and 60 ft for a combination vehicle (the semitrailer length is limited to 53 ft). Any vehicles exceeding these restrictions must obtain a permit prior to moving on Indiana highways.

If the vehicle exceeds any of the following limits, a "superload" permit is required: 16 ft in width, 15 ft in height, 110 ft in length and 108,000 lb in weight.

Ohio

The Ohio Department of Transportation (ODOT) has a standard set of design vehicles called "Ohio Legal Loads" that are used to rate all bridges in its inventory. These vehicles include the AASHTO HS20-44 design vehicle, and special vehicles with designations 2F1, 3F1, 4F1 and 5C1. The vehicle configurations are shown in Figure 3.1.

ODOT uses the Load Factor Method to calculate load ratings. ODOT's preferred software to perform bridge load rating analyses is AASHTO BARS. ODOT has made a personal computer version of this software available free of cost on its website. ODOT also accepts software such as BRASS, Merlin-Dash, STAAD, GT STRUDL, SAP 90 and SAP 2000.

Legal weight limits in Ohio are 80,000 lb for the gross vehicle weight, and individual axle weights are restricted based on the FHWA Federal Bridge Formula B. Vehicles exceeding 80,000 lb must apply for a "Routine Issue Permit" before traveling on Ohio highways. ODOT considers any vehicle with a total gross vehicle weight equal to or more than 120,000 lb to be a "Superload."

The legal size limitations are 13 ft 6 in, 8 ft 6 in, and 53 ft for height, width and length, respectively.

Ramifications of the North American Free Trade Agreement (NAFTA)

The table below shows current general truck size and weight limitations in the United States, Canada and Mexico.

Country	Overall Length	Trailer Length	Height	Gross Vehicle Weight (lb)	Single Axle (lb)	Tandem Axle (lb)	Tridem Axle (lb)
United States			13'-6"	80,000	20,000	34,000	
Canada	75'-5"	53'-0"		140,000		37,479	46,297
Mexico				146,600		42,990	49,604

International harmonization committees have been established under the auspices of the U.S. Department of Transportation to attempt to establish uniform limits, but because harmonization is not required under NAFTA, this effort has been unsuccessful thus far.

To date, the influence of NAFTA on the design or load rating of bridges has been virtually non-existent. Some states and provinces have raised the lower thresholds of weight and size limitations for overweight and oversize vehicles requiring permits, but these increases have resulted more from lobbying efforts by the U.S. and Canadian trucking industries rather than from influences due to NAFTA. However, if the harmonization committees establish uniform truck size limits in the future, it is a certainty that AASHTO will update their design loads and load rating criteria for bridges in the United States.

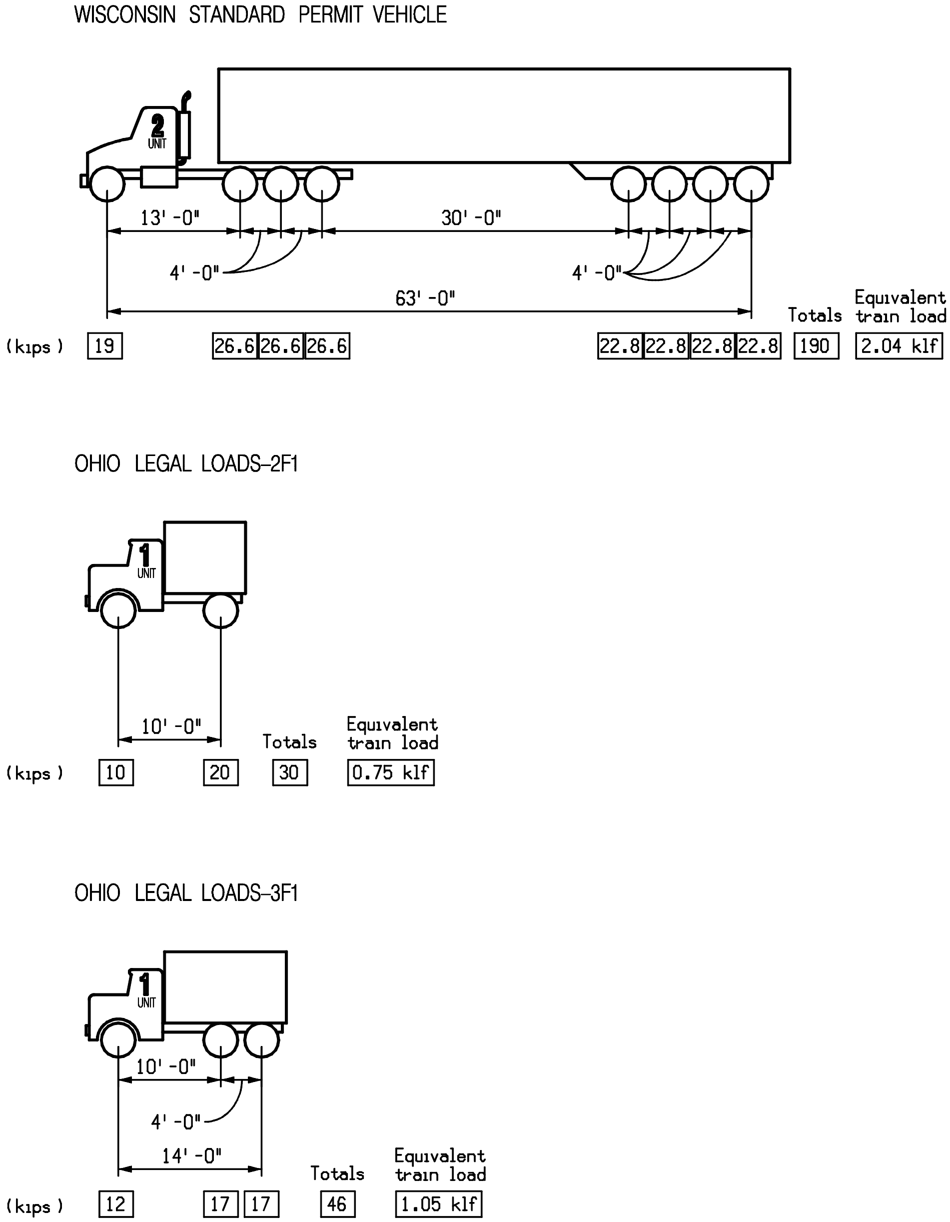
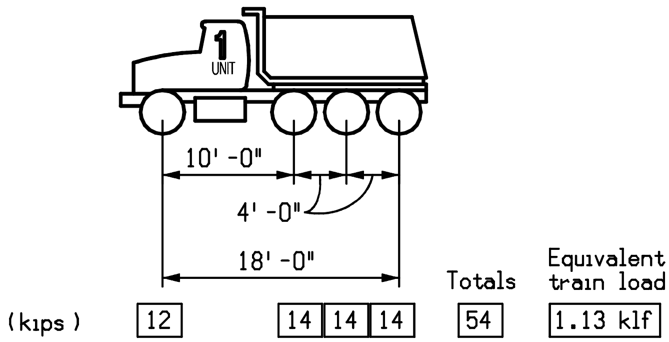
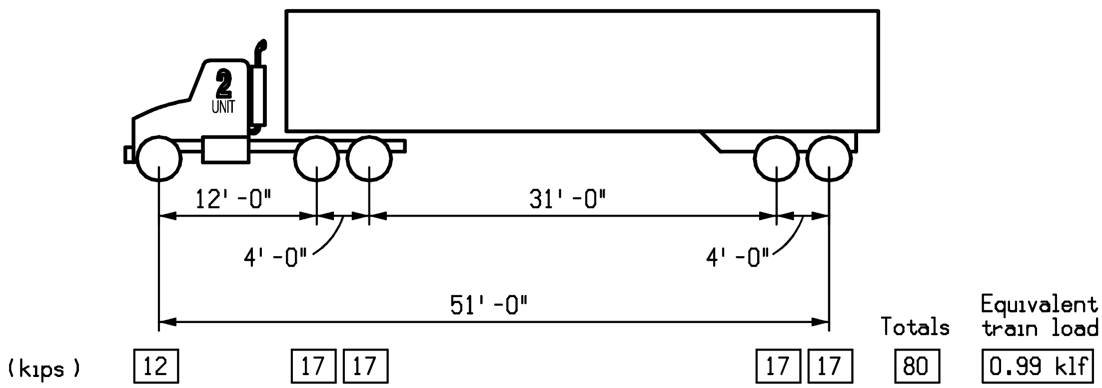


FIGURE 3.1
Legal Vehicles in Other States and Countries

OHIO LEGAL LOADS–4F1



OHIO LEGAL LOADS–5C1



ONTARIO EVALUATION LOADS–LEVEL 1

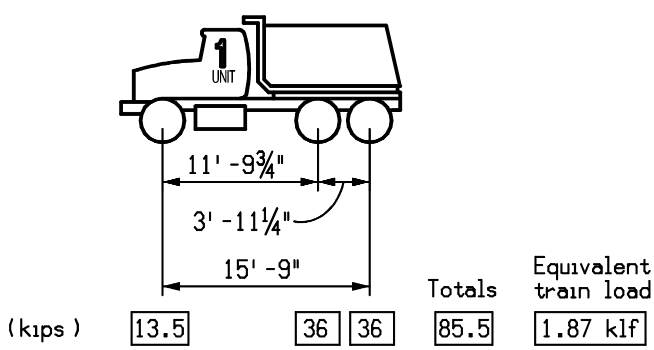
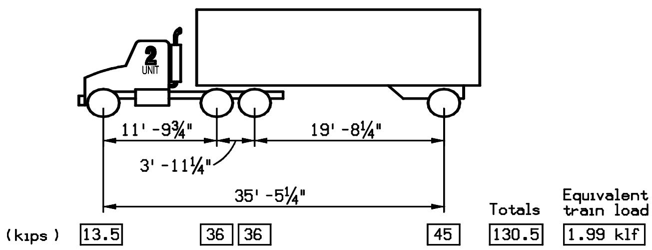


FIGURE 3.1 (Continued)
Legal Vehicles in Other States and Countries

ONTARIO EVALUATION LOADS–LEVEL 2



ONTARIO EVALUATION LOADS–LEVEL 3

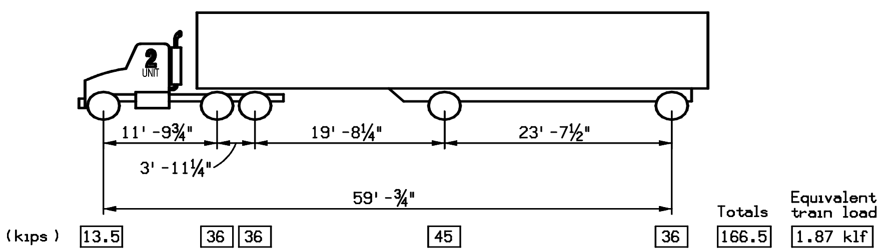


FIGURE 3.1 (Continued)
Legal Vehicles in Other States and Countries

Chapter 4

GENERAL ANALYSIS PROCEDURES

January 3, 2002

GENERAL ANALYSIS PROCEDURES

Purpose of Load Rating

The safe load carrying capacity of a bridge is determined through the load rating process. The bridge owner and, indirectly, the bridge user must be assured that each structure is being used in a safe and sustainable manner. Through load rating, it may be discovered that a bridge is incapable of safely carrying some legal loads. In that circumstance, it is necessary to publicly "post" the bridge for the reduced safe load or, in the extreme case, to close the bridge. In addition, for those occasions when loads beyond the range of standard legal vehicles (or "permit" loads) need to use a specific structure, load rating can provide answers about which loads are safely acceptable.

The requirement to perform load ratings on highway bridges stems from federal law and can be found in the *National Bridge Inspection Standards*, October 1988, within the Code of Federal Regulations. Specifically, Title 23, Part 650, Subpart C, 650.303 (c) reads:

> "Each structure required to be inspected under the Standards shall be rated as to its safe load carrying capacity in accordance with Section 4 of the AASHTO Manual. If it is determined under this rating procedure that the maximum legal load under state law exceeds the load permitted under the Operating Rating, the bridge must be posted in conformity with the AASHTO Manual or in accordance with State law."

In this context "AASHTO Manual" refers to Reference 1 (see Chapter 11).

Process Outline for Load Rating

The process of preparing a bridge load rating has many components. Perhaps the most significant items include gathering physical data for the specific bridge, selection of the appropriate truck type(s), choosing the correct live load distribution factor and performing the actual analysis.

<u>Information Gathering</u>

Basic information may be available from a variety of sources. Specific details regarding span length, beam spacing, beam size, material properties and other miscellaneous items is ordinarily available in the original design plans and/or as-constructed plans. If these sources are unavailable, an inspection of the bridge by a qualified inspector to measure pertinent details may be sufficient for an approximate rating. If a more exact rating is required, load tests may be necessary to determine the safe load capacity. Historical information regarding material properties is included in Chapter 10.

The existence, extent and thickness of any overlay on a bridge deck is of great significance when performing load rating calculations. Deck overlays are very common, and they can have a profound effect on that capacity of a structure which remains available for carrying live load. It is the responsibility of the bridge analyst to be aware of the details of any overlay which may exist on a structure to be load rated.

The condition of all structural components and extent of deterioration must be considered in the calculation of a load rating. This information may be available in a recent thorough field inspection. Inspections are to be performed as described in Section 3 of the AASHTO Manual for Condition Evaluation of Bridges. The effective area of members used in a capacity analysis must be the original gross area minus the area that can no longer carry load due to deterioration or corrosion.

Analysis Truck Selection

As can be seen in Chapter 2, there is a great variety of legal vehicles that use the roads and bridges in Michigan. Michigan law elaborates loads that fall in three categories: "Normal," "Designated" and "Special Designated." It is of primary importance to know whether a particular road or road system has been selected as "Designated" and/or "Special Designated." Bridges within a system that has no designation can be analyzed for "Normal" loads. A more conservative assumption would be to include all Michigan legal load categories in the analysis.

Tables showing maximum moments and shears caused by all three categories of loads are included in Chapter 10. Also, see Chapter 5 for an expanded discussion of vehicle selection.

LL Distribution factor

When using the Load Factor (LF) method, live load distribution factors vary greatly depending on beam spacing, bridge deck type and beam or girder type. Although this Guide focuses primarily on LF, there may be circumstances when the Load and Resistance Factor Design (LRFD) method will prove useful to the analyst. For more information about live load distribution factors, see Chapter 6.

Calculations

The final element in completing an analysis is performing and documenting the analysis calculations. For several examples of actual calculations, see Chapter 9.

Summary of AASHTO Manuals

Manual for Condition Evaluation of Bridges (Ref 1)

This manual is a very useful and thorough resource. The information contained in this MDOT Bridge Analysis Guide is based in large measure on information available in the AASHTO Manual. A summary of the chapters contained in the AASHTO manual is as follows:

• Chapter 1 - Introduction	This chapter gives a basic introduction into load rating.
• Chapter 2 - Bridge File (Records)	This chapter summarizes the types of records that should be kept for each bridge by the bridge owner.
• Chapter 3 - Inspection	Types of inspections are listed as well as frequency of, planning of and equipment for inspection operations.
• Chapter 4 - Material Testing	Testing of material may be necessary to determine material strength. This chapter describes various methods of testing.
• Chapter 5 - Nondestructive Load Testing	This chapter briefly explains that load testing is an option in lieu theoretical analysis calculations.
• Chapter 6 - Load Rating	The guiding principles of load rating calculations are contained in this chapter of the AASHTO manual.
• Chapter 7 - Additional Considerations	Other items such as sign posting, vehicle permits and historic bridges are discussed in this section.

<u>Standard Specifications for Highway Bridges, Sixteenth Edition</u> (Ref 2)

This AASHTO manual has been used to guide the direction of bridge design in the United States for decades. The purpose of the Standard Specifications is to “standardize” the way bridges are designed in the United States. Both Allowable Stress Design and Load Factor Design are covered in the Standard Specifications.

<u>Load and Resistance Factor Bridge Design Specifications</u> (Ref 3)

This newer manual was first published in 1994 and may someday supercede the Standard Specifications. The LRFD Specifications have been adopted by some states as the new “standard” for bridge design. Michigan has not yet adopted LRFD methods. However, much useful information is contained in this manual.

Summary of MDOT Manuals

Standard Specifications for Construction (Ref 9)

Past editions of the Michigan Department of Transportation Standard Specifications for Construction may be very helpful. These specifications may provide information useful in determining the original material properties of concrete, structural steel and steel reinforcement.

Bridge Design Manual and Bridge Design Guides (Refs. 11 and 12)

When existing plans of the subject bridge are unavailable, old editions of the MDOT Bridge Design Manual and Bridge Design Guides may provide useful information regarding the design techniques/criteria common to the year of the bridge.

Specifications for Design of Highway Bridges, 1958 Edition (Ref 30)

A complete description of bridge design practice at MDOT in 1958.

Road and Bridge Standard Plans

Similar to the Bridge Design Manual and Bridge Design Guides, older editions of Standard Plans may also provide helpful information. Old bridge railings are shown in detail in previous editions of the Standard Plans.

Structure Inventory and Appraisal Coding Guide (Ref 10)

This Guide is intended to aid local agencies in completing and submitting the Structure Inventory and Appraisal forms for all bridges in their jurisdiction.

Theoretical Analysis Methods for Load Rating

The three primary analysis methods for load rating bridges include: 1) the Allowable Stress (AS) method, 2) the Load Factor (LF) method and 3) the Load and Resistance Factor (LRF) method. All three will be briefly described. This Guide focuses primarily on the Load Factor Method. An additional method for studying live load distribution, finite element analysis, will be discussed in Chapter 6, Live Load Distribution.

It should be noted that Federal Regulations require that LF methods be used for Federal Inventory and Operating ratings. Michigan Operating and Permit ratings may be performed using any of the above methods.

ASD, sometimes referred to as Working Stress Design is oldest of the three methods introduced above. This was the design philosophy used in the earliest Standard Specification for Highway Bridges, issued by AASHO in 1931. In this method, service (or unfactored) loads are applied to the structure and used to determine stresses. The relationship between stress and strain is always taken as linear. The calculated stresses are then compared to an allowable stress. The allowable stresses are determined by applying a factor of safety to the yield stress or ultimate stress of the material. In ASD, live load is treated with the same importance as dead load.

LFD began to be implemented by AASHTO in the early 1970's. In the LFD methodology, various factors are applied to the loads to increase them based on the predictability of each load type. Load factors for live loads are higher than for dead loads because dead loads can be calculated fairly accurate, whereas, live loads are more unpredictable. In addition, reduction factors are applied to the strength of each structural member. These reduction factors lower the strength of the member based on the probabilities of achieving the planned for material properties and dimensional accuracy of the member, among other potential variables. LFD is also based on the knowledge that members continue to gain capacity beyond the linear stress versus strain stage. Member capacities are calculated with the member at full yield strength. LFD is viewed as a more rational and accurate method than ASD. Both ASD and LFD methods are contained in the current AASHTO Standard Specifications for Highway Bridges; however, LFD is more widely used.

LRFD as the most recent method for design and analysis of highway structures, began to be implemented in the 1990's. This method is an extension of the LFD theory. LRFD is more refined in terms of the use of probability and statistical data for both loads and member capacities. New live load configurations were developed and equations were rewritten to include current research. The AASHTO LRFD Bridge Design Specification is anticipated to someday replace the Standard Specifications that contains the ASD and LFD methods.

<u>Material Sampling for Strength Determination</u> In conjunction with theoretical analysis, field samples may be taken and tests conducted to determine the actual “as-built” strength of the structural components. For structural steel strength measurement, MDOT’s practice has been to take three samples from three different beams, usually from the bottom flange near an end support. Tensile testing should be done in accordance with ASTM A-370. Deck concrete may be cored and tested for compressive strength in accordance with ASTM C-39. A minimum of three cores should be tested.

If the results of these tests indicate that greater than anticipated strength is present, that greater strength can be used for analysis and rating of the bridge. However, if lower than anticipated strength is found, that result can not be ignored, and must be used in the rating process.

Actual steel and concrete strength results may be utilized with any approved analytical technique.

Load Testing Method of Load Rating

Load testing of bridges for load rating purposes is also a useful method in certain circumstances. Some bridges can not be satisfactorily analyzed due to a lack of design plans or because of deterioration that is difficult to quantify. In other cases, unusual structure types may not lend themselves to definitive analysis techniques.

A potential advantage of load testing is that some bridges have been shown to have a higher capacity using this method than that derived by normal calculations. An obvious disadvantage is that load testing is generally significantly more expensive than performing normal calculations. However, the cost of load testing may be acceptable to a bridge owner if faced with the possibility of a more expensive bridge replacement or major bridge rehabilitation.

To be useful in establishing (or proving) maximum safe live load capacity, "proof" load testing should be performed. The test load magnitude should be such that it will cause at least the Operating level of live load effects of the live load that would be allowed to use the bridge. For details regarding load testing procedures and methods of determining proof load test values see the Manual for Bridge Rating through Load Testing (Ref 31) Careful planning of loads needed, load application, instrumentation and personnel requirements should be carried out, prior to testing. A condition survey of the structure and an analysis to identify critical components should be completed as part of the planning. The bridge should be closed to traffic during proof load testing.

MDOT has sponsored load testing of various bridges throughout the state and has reports available. If load testing is appropriate for a given bridge, it may be helpful to obtain this information from MDOT. See Chapter 11 for specific references related to MDOT sponsored load testing.

Judgment Load Ratings

Generally, Judgment Ratings are performed with few or no calculations to support such ratings. An example of a judgment rating can be found in the text of Chapter 7 of the AASHTO Manual for Condition Evaluation of Bridges:

> "A concrete bridge need not be posted for restricted loading when it has been carrying normal traffic for an appreciable length of time and shows no distress. This general rule may apply to bridges for which details of the reinforcement are not known. However, until such time as the bridge is either strengthened or replaced, it should be inspected at frequent intervals for signs of distress. In lieu of frequent inspections, a bridge may be load tested to determine its capacity."

In all cases that a Judgment Rating is performed, it should be after a thorough visual observation of the bridge and with a clear knowledge of the traffic loading using the bridge. However, if signs of distress are observed, normal load rating procedures should be considered.

Judgment Ratings should be accompanied by written documentation that supports the conclusions of the Engineer. These documents should include copies of at least the following items: the inspection report, a detailed technical description of member condition (and damage if any exists), a technical description of the traffic that does or may use the bridge, any calculations made to rate the bridge and a listing of assumptions used as a basis for those calculations. Whenever possible, photographs should be included in the Judgment Rating documentation for further support.

<u>Substructure Considerations</u>

Section 6.1.2 of the AASHTO Manual for Condition Evaluation of Bridges gives guidance regarding substructure ratings. In essence, that section allows the engineer to use his/her judgment in the rating of substructures. If the substructure show no signs of instability or deterioration, then the substructures may be considered to be adequate for the existing traffic. However, if the substructure does show signs of deterioration and/or distress, the engineer should perform a conservative judgement rating.

<u>Deck Considerations</u>

In general, stresses in the deck do not control the load rating except in special cases, as noted in Section 6.7.2.1 of the AASHTO Manual for Condition Evaluation of Bridges. This is easier to understand if one compares the maximum axle load of an HS20 design truck, which is 32 kips, to the maximum normal legal axle load of 18 kips. In addition, bending in two directions, or plate action, is a known behavior of deck slabs that may have been excluded in the original design but does have a significant effect on the capacity of the slab.

However, some bridge deck slabs originally designed for H-15 loading may be over stressed by the tandem axles of Michigan Designated or Special Designated legal vehicles. AASHTO section 3.24.3.1 (ref 2) is based on a spread of the effect of individual wheel loads. Based on a study of the AASHTO method, for bridges with normal beam spacing, the moment effect of the wheels of tandem axles spaced at 3'-6" will overlap, and hence are additive.

It is appropriate to examine the Michigan Operating capacity of bridge decks designed for H-15 loading, which are exposed to Designated or Special Designated Michigan legal vehicles. See Chapter 9 for an example of an H-15 slab analysis. In general, examinations for Inventory Rating and for Federal Operating rating need not be conducted.

Simple Spans Versus Continuous Spans

The majority of bridges throughout Michigan is made up of simple spans. Simple spans have supports that allow the beam ends to rotate freely. Continuous spans have beam members extending over several supports. Continuous bridges have become more popular since deck joints can be eliminated thereby reducing future maintenance problems. All other details remaining constant, continuous beams can carry more load than simply supported beams. Simple span bridges are the general focus of this Bridge

Analysis Guide.

Overview of Computer Software

Available Software

Commercial software is available to aid in load rating calculations. Some of these software packages are available from AASHTO and some are available from private companies. Since computers and software change so rapidly, this Bridge Analysis Guide will not supply great detail with regard to software. Perhaps the best advice is to study the specific details prior to purchasing any software to be confident that the product that is chosen is capable of performing the functions that are desired. Most software manufacturers advertise their products in trade magazines. Each software manufacturer specifies the minimum system requirements that your computer must have to properly run their software. Most manufacturers now require Microsoft Windows 95 or higher, a CD-ROM drive, a mouse or other pointing device, a Pentium processor and a specified amount of hard drive space.

Listed below are some software packages that are currently available:

- *Virtis* is available from AASHTO, and was specifically created to aid in the load rating of highway bridges.

- *STAAD* is a program developed by Research Engineers International. STAAD is an acronym for Structural Analysis And Design and is a general analysis program that can be used for design as well as ratings.

- *SAP2000*, developed by Computers & Structures, Inc.; is another general analysis program that can be used for designing or load rating bridges.

- *DESCUS* is a software package that designs, analyzes and rates curved or straight steel bridge girders. Opti-Mate, Inc. is the company that produces DESCUS.

- *BRASS* is an acronym for Bridge Rating and Analysis of Structural Systems and is available from the Wyoming Department of Transportation.

Spreadsheets

With a few basic equations, an engineer can create a spreadsheet to aid in load rating calculations. Spreadsheets offer an inexpensive method to make use of the computer. An advantage that a spreadsheet has over using commercially available software is that it can be specifically tailored to individual needs and that the formulas, or code, can be easily checked, verified and modified. Spreadsheet concepts and operating details should always be verified by someone other than the originator.

Overview of Hand Calculation Methods

Superposition

The principle of superposition is often used in mechanics of materials and structural analysis. For example, in strength-of-materials studies, the total stress at a point in a material resulting from various applied forces can be obtained by summing the stresses due to each force considered individually. In determining the reactions of a simple beam subjected to a number of loads, the total reaction can be obtained by summing the reactions due to each load considered individually. The principle of superposition can be stated as follows:

> Principle of Superposition: The total effect at some point in a structure due to a number of loads applied simultaneously is equal to the sum of the effects for the loads applied individually.

For the principle of superposition to be valid there must be a linear relationship among forces, stresses and deflections. There are two conditions for which superposition is *not* valid:

1. When the structural material does not behave according to Hooke's law; that is, when the stress is not proportional to the strain.
2. When the deflections of the structure are so large that computations cannot be based on the original geometry of the structure (Ref 15).

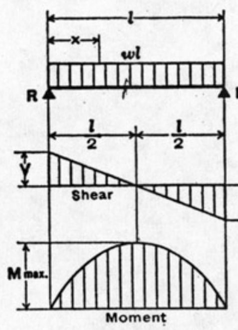
Unless otherwise stated, the principle of superposition is assumed to be valid in this Bridge Analysis Guide.

Beam Diagrams and Formulas

Many publications contain common beam loadings that can be used to analyze a variety of bridge superstructure loading scenarios. An example of two of the most common beam diagrams taken from the American Institute for Steel Construction (Ref 5) are shown below in Figure 4.1.

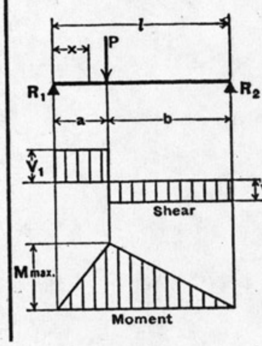
With the principle of superposition in mind, these beam diagrams can be added together in a variety of ways to reproduce dead and live loads for simple spans. An example of superposition can be shown in Figure 4.2.

SIMPLE BEAM—UNIFORMLY DISTRIBUTED LOAD



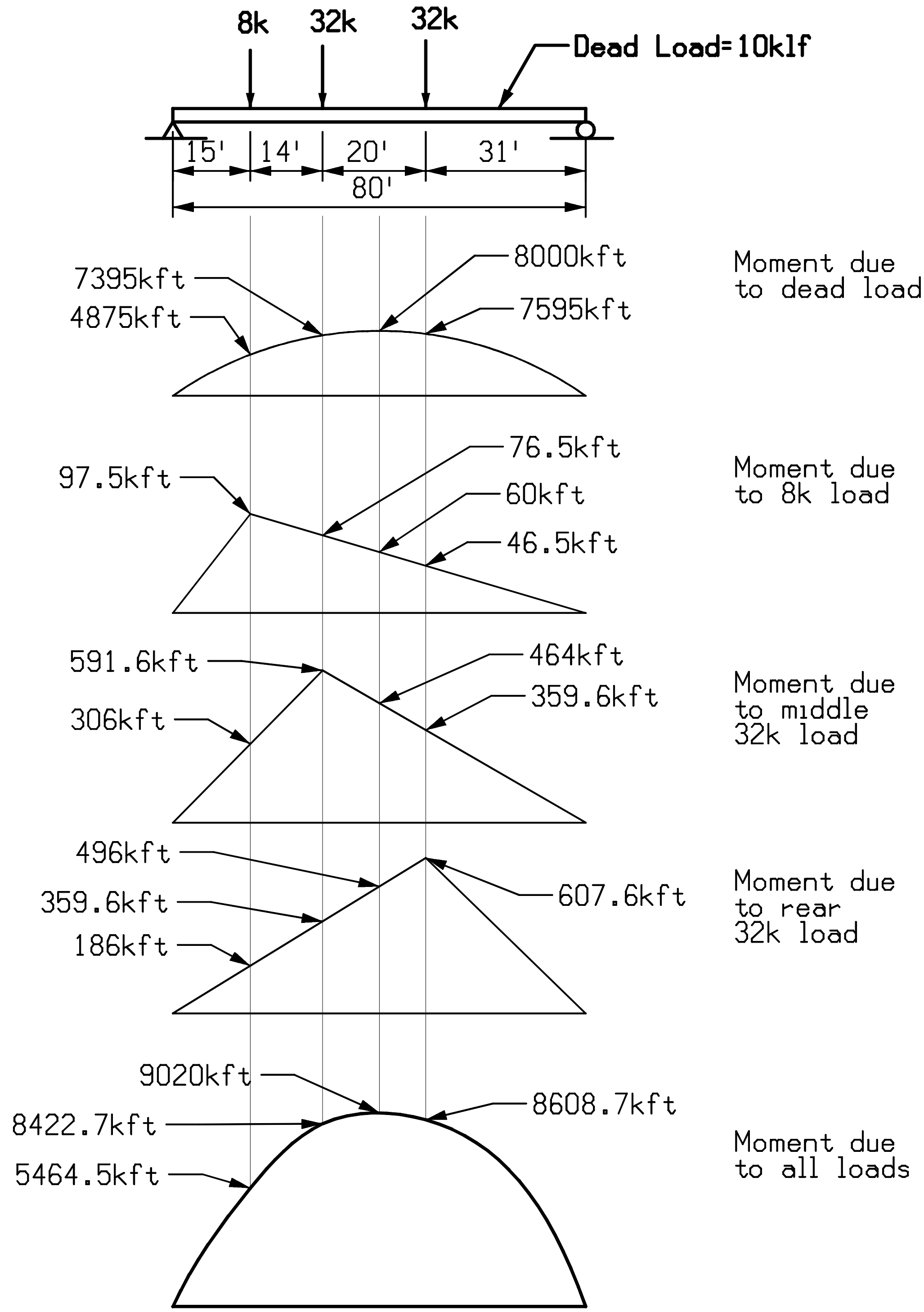
Total Equiv. Uniform Load . . .	$= wl$
$R = V$	$= \frac{wl}{2}$
V_x	$= w\left(\frac{l}{2} - x\right)$
M max. (at center)	$= \frac{wl^2}{8}$
M_x	$= \frac{wx}{2}(l - x)$
Δmax. (at center)	$= \frac{5wl^4}{384EI}$
Δx	$= \frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

SIMPLE BEAM—CONCENTRATED LOAD AT ANY POINT



Total Equiv. Uniform Load	$= \frac{8Pab}{l^2}$
$R_1 = V_1$ (max. when $a < b$)	$= \frac{Pb}{l}$
$R_2 = V_2$ (max. when $a > b$)	$= \frac{Pa}{l}$
M max. (at point of load)	$= \frac{Pab}{l}$
M_x (when $x < a$)	$= \frac{Pbx}{l}$
Δmax. $\left(\text{at } x = \sqrt{\frac{a(a+2b)}{3}} \text{ when } a > b\right)$	$= \frac{Pab(a+2b)\sqrt{3a(a+2b)}}{27EIl}$
Δa (at point of load)	$= \frac{Pa^2b^2}{3EIl}$
Δx (when $x < a$)	$= \frac{Pbx}{6EIl}(l^2 - b^2 - x^2)$

FIGURE 4.1
Common Beam Diagrams



Example: 9020kft = 8000kft + 60kft + 464kft + 496kft

FIGURE 4.2
Example of Superposition

Various beam diagrams also exist for fixed end moments and continuous spans. Using the same methodology as depicted in Figure 4.2 with superposition in mind, beam diagrams can also be used for continuous superstructures. For continuous spans, the engineer should be aware of the degree of fixity at each support and whether a beam diagram is appropriate. If it is determined that the degree of fixity at each support is such that it cannot be modeled using the standard beam formulas, then a more detailed analysis is needed. The Moment Distribution Method and differential equations are among other hand calculation methods available to the engineer, all of which are beyond the scope of this manual.

<u>Influence Lines</u>

Influence lines are another method used to calculate bending moments and shears. Influence lines can be defined as a function whose value at a point represents the value of some structural quantity due to a unit force placed at the point (Ref 15). Consider a three span continuous model. An influence line for determining the negative moment at the left interior support would appear similar to that shown below in Figure 4.3.

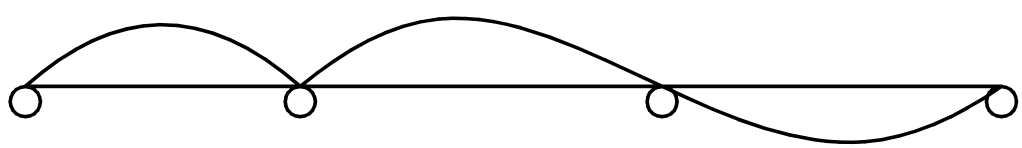


FIGURE 4.3
Example of Influence Line

Influence lines require careful forethought in order to understand which points are of significance and how to have the greatest effect on those points. One useful design aid is a publication called *Moments, Shears and Reactions for Continuous Highway Bridges*. This publication is produced by the American Institute of Steel Construction (AISC) and is quite useful for continuous structures. This publication gives influence coefficients that are derived from influence lines. Again, superposition can be used with influence lines. Though this publication was originally published in 1959, it is still available for purchase and can be obtained by contacting AISC or going to the website www.aisc.org.

Critical Locations on Beams

For simple spans, worst case moments will occur at or near midspan and worst case shears will occur at the supports. Evaluations of capacity versus applied midspan moments and end shears are the most important examinations for load rating of simply supported bridges. However, for bridges with continuous spans or with pin and hangers, critical sections are not as obvious and require careful analysis.

On simply supported structures two other circumstances may require an investigation of capacity at a location other than the two most important locations noted in the above paragraph. If a structural section change, such as a cover plate end or flange transition, occurs on a beam or girder, it may be necessary to examine the capacity of the reduced section versus the applied moment at that change location. Also, if significant deterioration has occurred at a location other than at midspan (for moment) or beam end (for shear) it may be necessary to evaluate the capacity of the member at that compromised location. Maximum moment and/or shear at these locations or any other location on a simple beam can be calculated using the AISC diagrams mentioned above. In addition, many currently available computer programs will generate the required information for any location on a beam.

Since the advent of high speed computers, the process of evaluating all appropriate live load configurations and placements has become much simpler. To determine the maximum bending moments and shears, each applicable vehicle must be “rolled” across the bridge. During this process, maximum values for bending moment and shear are recorded along a given span for each vehicle and for each placement. These tabulations of moments and shears for each vehicle are called “envelopes.” An example of moment and shear envelopes is shown in Figure 4.4. Once created, the envelopes for each vehicle can be compared to determine which vehicle produces the most severe loading effects for each span length. These maximums can be compiled into a chart for all applicable span lengths. A complete set of maximum charts is contained in Chapter 10 of this Guide.

Documentation of Load Rating

Reasons for Documentation

Documentation is important in load rating just as it is in most engineering calculations. Calculations create a written record of the basis for the load rating of a given bridge. It is recommended that a copy of all load rating calculations, along with any structure inspection information that formed a basis for the rating, should be maintained in a file for each bridge. This allows individuals in the future to refer to a previous load rating and see the assumptions that were used in that work. This information may also be helpful for future ratings.

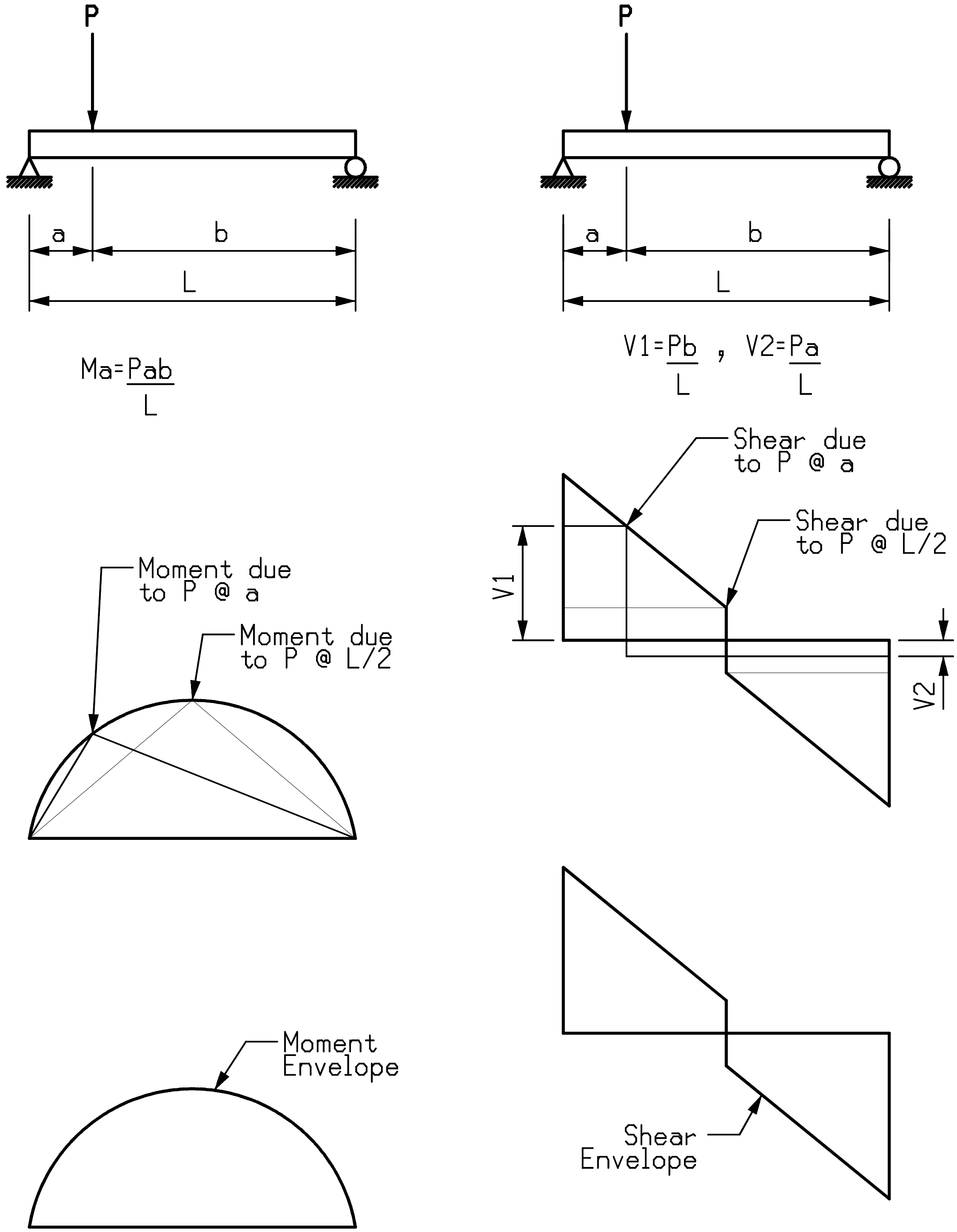


FIGURE 4.4
Example of Moment and Shear Envelopes

Documenting Hand Calculations

Hand calculations should be performed by a competent engineer familiar with bridge design. It is important that hand calculations be neat and orderly and accompanied by references to books, manuals, inspection information, test data or anything that was used to aid in the calculations. Assumptions should be noted to provide clarity. Hand calculations should be checked and ultimately sealed by a Professional Engineer licensed in the state of Michigan. A sample hand calculation is shown in Figure 4.5. When reviewing Figure 4.5, please note that the right edge of the paper is reserved for references to manuals and codes. Also note how results are clearly identified, equations are fully written out and units of measure are clearly labeled.

A summary of results should be prepared at the conclusion of all rating calculations. The summary should contain at a minimum: the inventory and operating capacities of the structure, the controlling member, and a description of any posting that may be required.

Documenting Software

Software can be used to significantly aid in the load rating of bridges. Software is especially useful for continuous or complex bridges. It should be noted that the engineer should be familiar with the capabilities and limitations of the software. When documenting software, the following information should be identified as a minimum: Name of software, version, manufacturer’s name and address.

A printout of the final input and output should be included in the file. Important results should be highlighted on the output for easy review. A diskette with the electronic input and output files should be included in the files. Significant limitations that affect the results should be documented.

It is important that the input and output be checked to verify that the software is running correctly. The input should be checked to verify that all parameters are entered correctly. The output should be checked for “reasonableness.” The reasonableness check requires a certain level of experience. Also, rough hand calculations can be performed to approximate output values. Software should not be used blindly.

Documenting Assumptions

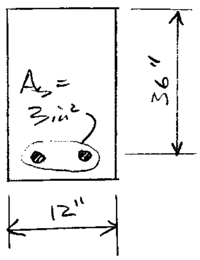
Any assumptions that are made during load rating should be clearly identified as being such. When possible, assumptions should be accompanied by a brief statement that substantiates the assumption.

URS

Job MAIN ST, BRIDGE OVER BIG RIVER	Project No.	Page ___ of ___
		Sheet ___ of ___
Description LOAD RATING	Computed by JOHN DOE	Date 1/23/01
	Checked by JANE DOE	Date 2/12/01
		Reference

BEAM ANALYSIS

SHEAR CAPACITY



$\phi V_n = \phi(V_c + V_s)$ — AASHTO 8.16.6.1.1

NO SHEAR REINF'$\Rightarrow$ $V_s = 0$

$\phi V_n = \phi V_c = \phi\, 2\sqrt{f'_c}\, bd$ — AASHTO 8.16.6.2.1

$= 0.85(2)\sqrt{3000}(12")(36")$

$\boxed{\phi V_n = 40224.7 \text{ lbs}}$

MOMENT CAPACITY

$a = \dfrac{A_s f_y}{0.85 f'_c b} = \dfrac{3 in^2 (60 ksi)}{0.85(3 ksi)(12")} = 5.9"$ — AASHTO 8.16.3.2.1

CHECK $\epsilon_s > \epsilon_y$, $\epsilon_y = \dfrac{f_y}{E_s} = \dfrac{60 ksi}{29000 ksi} = 0.00207$

$c = \dfrac{a}{\beta_1} = \dfrac{5.9}{0.85} = 6.9"$ — AASHTO 8.16.2.7

$\epsilon_s = \left(\dfrac{d-c}{c}\right)\epsilon_u = \left(\dfrac{36-6.9}{6.9}\right).003 = 0.0127$ — NILSON p80

$\epsilon_s = 0.0127 > \epsilon_y = .00207$ ✓

$\phi M_n = \phi A_s f_y (d - a/2)$ — AASHTO 8.16.3.2.1

$= (0.9)(3 in^2)(60 ksi)(36 - 5.9/2)\ 1/12"$

$\boxed{\phi M_n = 446.2 \text{ k·ft}}$

FIGURE 4.5
Hand Calculation Example

Chapter 5

ANALYSIS VEHICLE SELECTION

June 30, 2006

ANALYSIS VEHICLE SELECTION

Summary of Vehicle Selection Concepts

The intent of this chapter is to aid in vehicle selection and vehicle placement in order to generate maximum live load moments and shears as part of the load rating process.

Determining the appropriate vehicle for load rating of bridges can be a time consuming effort. In general, for short span bridges, individual axle loads and spacings are very critical. As spans increase in length, the individual axles of a vehicle become less significant while the vehicle's gross weight becomes more critical in generating maximum effects. Chapter 4 of this Guide addresses the placement of vehicles to create maximum moments and shears. In addition, many structural engineering text books give a methodology for placement of moving loads.

Vehicle Selection Guidelines

There are five general categories of bridge rating discussed in the Guide. These five categories use three different groups of live loads.

<u>Inventory Rating and Federal Operating Rating</u>.

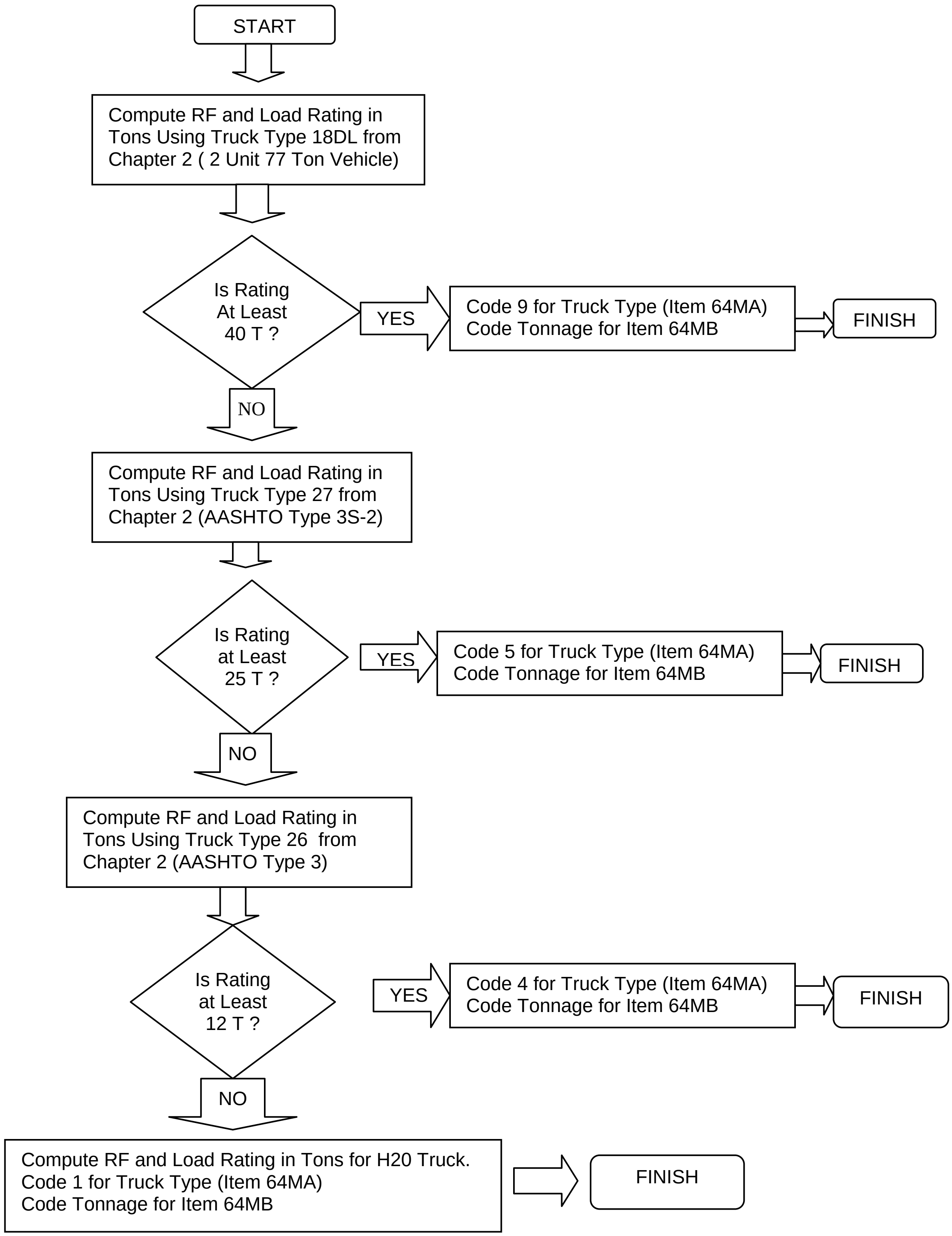
For both of the above ratings, the live load used to rate each structure is to be HS20 truck or lane load as defined in the AASHTO Design Specifications, and as shown in Figure 2.2.

In general, the truck load controls for shorter span lengths and lane load controls for longer lengths. Lane loadings may be continuous or discontinuous. Only one standard truck per lane is allowed on a span. As many lanes may be loaded as is required to produce the maximum desired affect. See Chapter 10 for a complete listing of maximum moments and shears for all span lengths between 5' and 300'.

<u>Michigan Operating Rating</u>.

The purpose of the Michigan Operating Rating is to provide a fairly uniform performance measure of the structure's load carrying capacity relative to the unique legal loads in Michigan. A convention has been used to determine which vehicle to select for reporting this bridge capacity in the Michigan Bridge Inventory. This convention is more easily understood by following the flowchart on the following page.

TRUCK SELECTION FOR MICHIGAN OPERATING RATING



For spans less than 200' in length, the vehicles shall be applied one per lane, with as many lanes loaded as is required to produce the maximum desired affect.

For spans 200' and greater, one lane shall be occupied by a train of any of the legal vehicles described above with a nose to tail spacing of 30 feet. This train can be idealized as a distributed load specific to each vehicle type. See Figure 2.2 for distributed load values of the equivalent train load for each vehicle. Additional lanes shall be loaded with one legal vehicle (the same legal vehicle as is used for the equivalent train load) per lane, with as many lanes loaded as is required to produce the maximum desired affect. For the circumstance where live load varies between adjacent lanes, standard live load distribution factors for interior beams are not applicable. See chapter 6 for live load distribution for this circumstance.

<u>Posting Load Rating</u>.

The live load used to rate each structure is to be any and all of the state legal vehicles and the three AASHTO legal vehicles, as shown in Figure 2.1.

The methods presented in this Bridge Analysis Guide contain a significant change in process for calculating the Posting Loads for bridges. This is due to a careful examination of the effects caused by the large number of legal axles configurations and axle weights allowed by Michigan law. The truck figures shown in Chapter 2 illustrate the legal configurations of 1-unit, 2-unit and 3-unit vehicles allowed in Michigan.

The analyst must determine the legal loads allowed by the jurisdiction for the bridge being investigated. In general, counties and cities in Michigan allow Designated Loading on their roads and bridges, so the following discussion is limited to Designated Loading. If a particular agency allows only Normal Loading, or allows Special Designated Loading, the process described below remains the same, however tables for Normal Loads or Special Designated Loads would be used.

When calculating the Posting Load Rating for a particular structure, after finding the live load capacity of a particular bridge, it may be found that many, or even all of the legal loads can not be safely carried by that bridge.

Using 1-unit vehicles shown in Chapter 2 as an example, the analyst will note that there are five different configurations of Michigan Legal Loads and an AASHTO 1-unit load (which is also legal in Michigan) for a total of six configurations. If for a particular bridge, it is found that any of these trucks can not be safely carried, it is then important to find which Michigan Legal Load should be used to calculate the Posting Load Rating. Each of the legal vehicles could be used to calculate this Rating Load and the Rating Load calculated based on each vehicle would be different.

A study has shown that for every span and capacity circumstance there is one truck that will yield the <u>lightest Posting Load Rating.</u> It is important to identify and use this particular “controlling vehicle” to calculate the Posting Load. This is important since truck operators, in general, do not know which of the 6 legal 1-unit vehicles they are driving, nor should they be asked to stop and make this determination before crossing a posted bridge. It would also be impractical to prepare posting signs for all six 1-unit vehicles, plus all 15 2-unit vehicles, plus all seven 3-unit vehicles.

To aid in determining which of the 1-unit trucks is the “controlling” vehicle, tables are available in Chapter 10 which list the moment and shear for every legal vehicle and for all span lengths between 5' and 300'. In addition to the live load moment, a value for Moment divided by Weight has been calculated for each of these combinations. To determine the “controlling” vehicle, the analyst should examine the values for the variable Moment divided by Weight for all vehicles which exceed the capacity of the section in question. The vehicle with the largest value for Moment/Weight is the “controlling” vehicle and should be used to determine the Posting Load. The same statements are true for shear analysis.

The same statements and methods apply to 2-unit and 3-unit vehicles. See the general example included in Chapter 9 for more clarity regarding the method for determining the “controlling” vehicle.

In the circumstance where all vehicles in a particular category (1-unit, 2-unit, 3-unit) can be safely carried by a bridge, the Posting Load will be the largest legal load in that category. In this circumstance, Posting would only be required if all vehicles in another category could not be safely carried by the bridge.

It must be noted that the above method is only applicable for simply supported beams. For bridges with continuous beams, it will be necessary to evaluate the effects caused by each of the legal vehicles in order to determine which vehicle will control the Posting Loads.

For spans less than 200' in length, the vehicles shall be applied one per lane, with as many lanes loaded as is required to produce the maximum desired affect.

For spans 200' and greater, one lane shall be occupied by a train of any of the legal vehicles described above with a nose to tail spacing of 30 feet. This train can be idealized as a distributed load specific to each vehicle type. See Figure 2.2 for distributed load values of the equivalent train load for each vehicle. Additional lanes shall be loaded with one legal vehicle (the same legal vehicle as is used for the equivalent train load) per lane, with as many lanes loaded as is required to produce the maximum desired affect. For the circumstance where live load varies between adjacent lanes, standard live load distribution factors for interior beams are not applicable. See chapter 6 for live load distribution for this circumstance.

Permit Load Rating.

This capacity rating is used when a request has been made to transport a load that is not included in the Michigan legal loads. The load to be carried may have heavier axles or more closely spaced axles than allowed by law, larger gross weight than allowed by law, or a combination of these features. The load to be used for analysis should be the exact load requested to be transported, with that one vehicle placed so as to produce the maximum desired effect. For permit rating, the bridge capacity can be evaluated at the operating level.

See Chapter 8 for a chart illustrating the more common permit type vehicle configurations. See Chapter 10 for tables for all maximum moments and shears for these loads, for span lengths between 5' and 300'.